Sensor Embedding in Additive Manufacturing (SEAM) Team

By DON Innovation

As one of the teams selected to participate in the Naval Air Warfare Center Aircraft Division's inaugural Innovation Challenge in 2015, the Sensor Embedding in Additive Manufacturing (SEAM) Team project established a novel solution for monitoring the structural health of additively-manufactured (AM) metallic parts.

Comprised of new hires with three years or less in the Navy, and with a wide variety of skills and technical backgrounds, the SEAM Team was granted six months and a small material budget to accomplish their mission.

The team consisted of materials engineer and team lead Denise Orthner, electrical engineer Kamal Bhakta, mechanical engineer Nicholas Cavaliere, and electrical engineers Ian Gallagher and Steven Orciuolo.

The team demonstrated that such embedded sensors could be an important enabling technology for condition-based maintenance of AM components. Since operations and support costs represent the largest cost driver for both ships and aircraft, this technology could reduce a significant amount of total ownership costs.

Another benefit of the technology is that embedded sensors can perform in harsh environments where external sensors may not survive. Since much of the Navy's equipment performs in highly corrosive environments with extreme thermal and shock loading, embedded sensor technology could support a shift from schedule-based maintenance to condition-based maintenance, increasing readiness and operability of naval systems.

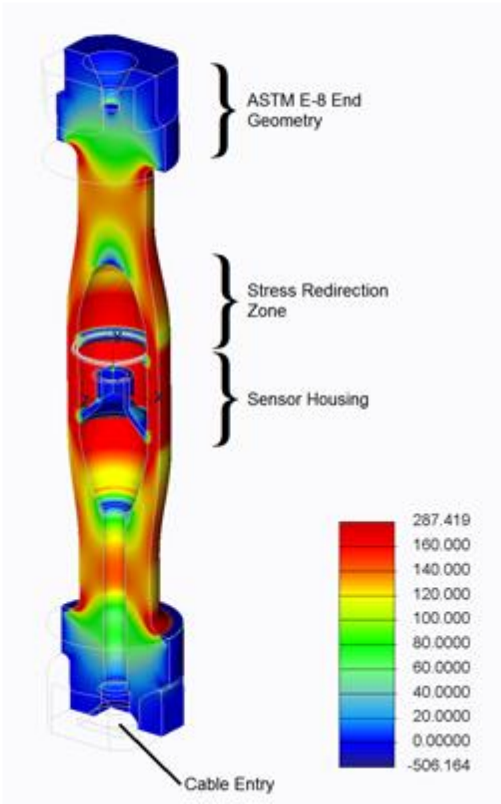
The SEAM Team focused on sensing strain in a test specimen. Meeting their goal required several questions to be answered, including:

- What technologies are suitable for embedded sensors?

• Can the embedded sensor perform just as well as a traditional strain gauge?

• Can the embedded sensor survive the AM process?

The team used a standard tensile specimen to accurately benchmark their results and made necessary alterations to accommodate an internal cavity for the sensor. Utilizing 4340 steel powder in a direct metal laser sintering machine, the team AM-printed 16 specimens containing different optimized designs. Each specimen was pull-tested until it fractured in order to determine the sensor's range, resolution, error and how the cavity reduced overall tensile strength.



Throughout the project, the SEAM Team demonstrated a high level of innovation. They developed an original sensor concept called a microwave frequency cavity resonator (MFCR). In this concept, a radio frequency wave was transmitted into the cavity. As the specimen changed length due to the applied forces, the change in cavity length correlated to the change in a resonant frequency, which was detected from the inside.

"The MCFR strain sensor can be compared it to a guitar string," explained Bhakta. "The guitar string vibrates at a resonant frequency -- an audible pitch -- based on the length at which the string is held. As the length changes, so does the pitch."

Without complex modeling tools, the team determined the ideal parameters for impedance matching. In one instance, they iteratively filed down the antenna length and adjusted the cavity length until it achieved resonance.

In another example, the SEAM Team had to create a geometry for the sensor cavity that protected the sensor from tensile loads. Since this method had never been previously attempted, the team could not leverage existing knowledge.

"If you were to open a dozen textbooks and look for 'internal cavity design,' you wouldn't find anything," said Cavaliere. "Up until now, the technology to do it hasn't existed."

The team referenced fluid dynamics using the analogy of water flowing around a rock to conceive a geometry where tensile loads "flowed" around an almond-shaped area. This process naturally created a "lea" that minimized the loads on the sensor.

"When you think of 3D printing, one of the first things you think of is novel geometries that have never been possible before for these materials," said Orthner. "But when printing in metal, there are also limitations for things that might seem simple. For instance, you can’t print an unsupported overhang.”

Additionally, the team designed a custom build plate that allowed for near-perfect realignment in the AM printer while removing it to install the sensor. This customized piece was critical to ensuring part integrity when interrupting the build process for the sensor installation. The team also developed a way to use the AM machine's own laser to weld a cap onto the sensor cavity.

Ultimately, the SEAM Team achieved its goal by developing and testing a proof-of-concept embedded sensor technology that was both reliable and repeatable. Their embedded sensors outperformed conventional strain gauges while minimizing the structural impact of both the cavity and the integration process on the specimen. The SEAM project is still in the research phase, and the technology is evolving.